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6/11/03

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NUMBER OF PAGES INCLUDING THIS SHEET: 15

RESPONSE TO DETAILD ACTION

Oath/ Declaration

The examiner identifies defects in the oath and noncompliance with 37 CFR 1.67(a). In particular, the examiner points out that the box labeled "A petition has been filed for this unsigned inventor" should not be checked. Furthermore, the examiner addressed the requirement to identify the application number and the filing date for the new inventive disclosure of Little. As a result of these identified defects, I, the applicant, have made the necessary corrections by complying with 37 CFR 1.67(a) and MPEP § 602.01 and 602.02, where with I resubmit forms without checking the labeled box: " A petition has been filed for this unsigned inventor". Furthermore I correctly identify this application by the application number and filing date.

Content of Specification

The examiner identifies a lack of a Brief Description of Several Views of the Drawing(s) in compliance with MPEP § 608.01(f). As a result of this identified absence of description of drawings, I, the applicant, have included this required Brief Description of Several Views of the Drawing(s) for inclusion in the original specification of the disclosure.

Claims Rejections – 35 U.S.C. § 112

On the basis of the first paragraph of 35 § U.S.C. 112, the examiner rejects claims 3, 5-13, 15-23 due to insufficiently provided enablement for this process to take place at "any temperature", "any pressure", "any flow rate" , ect. Due to the said deficiencies, the operability of the invention on the whole scope of claimed conditions is questioned. As a result of these identified faults of the original claims, I, the inventor, modify the claims by limiting the scope so as to take rights concerning the use of dynamic magnetic fields over processes operated within reasonable temperature limits (as previously disclosed by

prior CVD, laser vaporization and arc vaporization methods of CNT and filament formation), so as to limit the scope of the thermal conditions but reserve rights over limited use of dynamic magnetic fields to enhance CNT and filament formation.

On the basis of the first paragraph of 35 § USC 112, the examiner rejects claims 4 and 14, " because the specification while being enabling for the process of chemical vapor deposition does not reasonably provide enablement for the process of arc discharge, physical vapor deposition or laser ablation". Because I do not mention PVD systems in the disclosure, I agree that I do not enable the PVD technique for magnetic formation of CNT. I accord with the examiner, the inventor also understandably limits the enablement of the invention to arc vaporization and laser vaporization systems to systems that employ metal in the target precursors. The enablement is limited to AV and LV systems using metal because it is only in these systems that related CCVD phenomena develop during the process similar to normal CCVD techniques. How ever, I beg the examiner to reconsider my claims over AV and LV systems containing TM on the basis that CCVD phenomena occur on metal particles formed in these systems as in the genuine CCVD systems. Although it is true that I focus mostly on catalytic chemical vapor deposition (CCVD) in the specification and identify the CCVD as the more suitable system to apply external magnetic fields for affecting CNT and filament formation, I do however discuss aspects of all three methods: catalytic chemical vapor deposition (CCVD), laser vaporization (LV) and arc vaporization (AV). More specifically, I, the inventor, directly discuss the arc method in paragraphs 17, 25,26,27,29,30,31,35,47,48,49. I discuss the laser method in paragraphs 32,48, and 49. In a number of instances, I discuss the plasma, which includes both arc plasmas and laser plasmas. In considering the AV and LV methods and mechanisms of CNT and filament formation in these systems, I anticipate similar catalytic processes on formed metal and metal carbide particles in these LV and AV systems as that occur on metal particles in CCVD systems. More specifically, in paragraph 49, I specifically disclose: " As the plasma cools [in LV and AV systems] metal nanoparticles nucleate and carbon species undergo catalytic chemical transformations to form graphite on the metal nanoparticles. The high temperature of the plasma, [the] nature of the nucleated metal nanoparticles and the electric and magnetic fields in the plasma contribute to hydrocarbon conversion to graphite." It is important that I specify and identify two key

ingredients in this paragraph 49: the formation of metal nanoparticles and the presence of magnetic fields. In other words, the LV and AV systems form carbon and metal atoms that develop into clusters and particles and further develop into CNT. I reveal that by forming metal-carbon particles, the LV and AV systems develop into CCVD systems. In paragraph 50, I more explicitly relate similar particle and catalytic activities in CCVD and LV and AV, allowing only for differences associated with how particles form in these three systems, I do not allow for different catalytic phenomena on these particles. I only allow for different particle formation scenarios such that particles form during arc and laser vaporization techniques but particles pre-exist during the CCVD techniques. In paragraph 50, I therefore stress CCVD differs from AV and LV in that the particles are preformed in CCVD where as they form during the LV and AV processes. The forming particles in the LV and AV systems undergo CCVD processes just as in the original CCVD itself. I point out that it is just more difficult to reinforce intrinsic magnetic effects in the more dynamic AV and LV methods relative to the more static CCVD method. Although I point out the difficulty of using magnetic fields in AV and LV methods, I associate similar magnetic effects in these systems also by identifying the magnetic ingredient. By identifying the ingredients, the disclosure enables the power of magnetic fields for forming the CNT and filaments in the AV and LV methods as well. I therefore identify two key ingredients (metal nanoparticles and magnetic field) of the invention with the AV and LV systems also. Furthermore, I note similar magnetic phenomena occur to enhance CNT and filament formation on metal nanoparticles in AV and LV systems just as occur in CCVD systems. However, I describe different physical and chemical scenarios in the plasmas of AV and LV systems relative to CCVD systems. These different environments in the plasmas allow less effective magnetic reinforcement. I therefore limit the magnetic effect in LV and AV, but I do not reject the possibility. I then more thoroughly demonstrate the effect in CCVD. However, by identifying (paragraph 49) the two key ingredients (the presence of magnetic field and metal nanoparticles) in all three methods and by linking these ingredients and their impact on LV and AV methods to identical active ingredients and impacts in the CCVD methods, I, the inventor, more explicitly demonstrate (beyond mere anticipation) the common effect of the magnetic power for causing CNT and filament formation in all three systems CCVD, LV, and AV.

It is on this basis that I believe my specification enables for AV and LV methods. I ask on these grounds that the examiner, please reconsider the enablement of the invention for AV and LV systems just as the CCVD system is enabled for this purpose of magnetic enhanced formation of CNT and filaments.

I beg the examiner to reconsider the disclosure on the merit that it focuses on the art of the magnetic field for affecting the CNT and filament formation and not the CCVD , AV, or LV scenario. This merit of the disclosure is expressed specifically in paragraph 53, which enables the general use of magnetic environment for enhancing steps involved in CNT and filament nucleation and growth. As discussed below in this defense, in particular, the disclosure demonstrates with more details the use of dynamic magnetic field to enhance CNT and filament production. By a detailed consideration of magnetic phenomena and the magnetic dynamics in metal particles and effects of reinforcing the magnetic phenomena via external dynamic fields in these particles and the resulting effect of the intrinsic and external magnetic field and the magnetic field dynamics on metal and carbon atoms during steps associated with CNT and filament formation, the disclosure enables the magnetic field and the magnetic field dynamics for enhancing CNT and filament formation. Thus it is the dynamic magnetic field that is the subject matter of this invention as already acknowledged by the examiner in the detailed office action. Therefore just as the magnetic field is claimed with a CCVD method and considering the disclosure links crucial events involving metal particles with magnetic powers in the AV and LV systems to similar causes, effects and agents in the CCVD system, I implore the examiner to reconsider the enablement and I claim intellectual rights over magnetic effects in all these systems. Whether the particle and/or field affecting the carbon atoms exist in CCVD, LV or AV methods is secondary. The primary fact is that the magnetic field and the field dynamics affect the carbon and metal atoms during CNT and filament nucleation and growth in such a away so as to allow judicious enhancement of this nucleation and growth.. The magnetic environment may exist or be reinforced in CCVD, LV, or AV systems. The disclosure considers more thoroughly the CCVD method (because really some CVD is occurring in all the methods), but this illustration by CVD consideration does not limit rights concerning magnetic phenomena only to CCVD. However, it is true that the disclosure considers CCVD more closely considering it more effectively for

impressing magnetic effects on the mechanism. I, the inventor, more explicitly demonstrate the effect in CCVD and further relate beyond mere anticipation similar effects in AV and LV methods. It is on this basis that I believe my specification enables for AV and LV methods as well.

On the basis of the first paragraph of 35 § U.S.C. 112, the examiner rejects claims 1 and 12 due to the indefinite nature for failing to particularly point out and distinctly claim the subject matter, which the applicant regards as the invention. The subject matter identified by the examiner is the magnetic field. As previously described and expressed, I emphatically agree and concur with the examiner that the magnetic field is the subject matter of the invention. Since we both agree that the magnetic field is the subject matter of the invention as is demonstrated in this disclosure of Little, I again beg the examiner to reconsider my claim over using the invention in the arc vaporization and laser vaporization techniques (as well as the agreed CVD), wherein the external magnetic fields (the subject matter) has been enabled by association to its similar power in all three systems to enhance the CNT and filament formation. I ask on the grounds that it is dynamics magnetic field effect that is the essence of the invention and not the arc vaporization or laser vaporization techniques or even the chemical vapor deposition technique in and of themselves. It is the application of an external dynamic magnetic field of sufficiency to affect the electronic structures of atoms in the system that is the subject matter. Whether these metal and carbon atoms are in CCVD systems, laser vaporization or arc vaporization systems is secondary. In addition to my agreement that the magnetic field is the subject matter of the invention, I concur with the examiner that the magnitude of the field should be better communicated. Therefore I am modifying the claims to include a more limited field intensity range, such that the field is sufficient so as to affect the electronic spins in carbon and metal atoms, whether the atoms are processed in the plasma of the AV or the LV systems or the metal solution of the CCVD method or the growing clusters and/or CNT and filament. It is important to make a point of distinction here from Harutyunyan et al. The originality of this disclosure is to use the field of such high enough intensity so as to affect the electronic states of metal and carbon atoms under prevailing thermal conditions in whatever system of interest. This purpose and use of the field is distinct from the purpose of Harutyunyan et al. and their use of much weaker magnetic fields to more simply immobilize and confine the catalyst. I beg the examiner to reconsider the two disclosures of Little and Harutyunyan et al as truly brilliant but moreover

absolutely different inventions. The absolute difference between Little's disclosure and that of Harutyunyan et al. is the magnetic field strength. It is much easier although vary desirable to confine the catalyst particle as disclosed by Harutyunyan et al. However, it is much more difficult to effect magnetic fields to drive electronic rearrangement of carbon and metal atoms of the catalyst as disclosed by Little. Little therefore requires much more intense magnetic fields ($>10^{-1}$ T). Moreover Little's disclosure requires varying magnetic fields, something Harutyunyan et al never mentioned (and something that would actually defeat their purpose of confinement). Therefore in accord with the examiner, I should be more specific on the intensity of the fields. I stress fields in excess of 10^{-1} T. On the other hand, Harutyunyan et al stress much weaker magnetic fields (1 orders of magnitude weaker) 10^{-2} T for the sole purpose of immobilizing the catalyst. Previously intense and strong magnetic field implied enough strength so as to affect electronic states of carbon atoms in the plasmas or metals and/or the growing clusters and CNT. Here I explicitly state the meaning of intense and strong magnetic field so as to illustrate the effect not to limit the scope of the disclosure, just as the examiner so thoughtfully requires.

On the basis of the appropriate paragraph of 35 § U.S.C. 102(e), the examiner rejects claims 1 and 2 due to the suggested anticipation of these claims by Harutyunyan et al. (USPGPUB 0053344). Although one aspect of Haturyunyan et al is slightly related to the invention disclosed by this application, the referenced disclosure (of Haturyunyan et al.) by the examiner represents only a very narrow scope of this new disclosure of Little presented and defended in this document. This narrow overlap with Harutyunyan et al. pertains to the use of the magnetic field to immobilize the catalyst during normal chemical vapor deposition of CNT and filaments. Harutyunyan 's disclosure only uses the external magnetic field to immobilize the catalyst in conjunction with their alleged unrelated catalytic mechanism of the CNT and filament formation. Actually they express to avoid magnetic field strength so strong so as to interfere with intrinsic CCVD mechanism of the catalyst. I, on the other hand, disclose to use only powerful enough magnetic fields to drive the intrinsic mechanism. Harutyunyan et al. express the limited purposes of their disclosure are to resolve the problem of catalyst migration, to resolve the problem of CNT purification, resolve the problem of tube destruction during purification and to resolve the problem of loss of catalyst. These ambitions of Harutyunyan et al in no way require magnetic influence over the intrinsic mechanism of

CNT and filament formation. In so doing, Harutyunyan et al. emphasize the use of the magnetic field to increase yield, throughput, re-use catalyst, improve separation and reduce damage to CNT product by immobilizing the product and catalyst during formation not driving the intrinsic mechanism magnetically. Harutyunyan et al. therefore only enable the immobilization of the catalyst in their disclosure as expressed by 0013: "In accordance with the present inventive apparatus, a device is positioned near the metal catalyst that is capable of generating a magnetic field. The magnetic field is useful for affecting or influencing the catalyst as by substantially inhibiting the mobility of the metal catalyst during the formation of the carbonaceous article from the precursor. The apparatus of the present invention advantageously restricts the mobility of the catalyst thereby reducing contamination of the produced products and improves efficiency and yield of the product per catalyst by reducing the loss of the catalyst I the product." All throughout their disclosure, Harutyunyan et al. focus on the reduced loss of CNT due to less needed purification steps and high recovery of catalyst. In 0025 and 0026 of the disclosure of Harutyunyan et al., the invention is contemplated and the achievement of the invention is expressed: "The present invention contemplates a new techniques to substantially inhibit if not eliminate the mobility of catalyst during formation of such products... The present invention advantageously reduces or completely eliminates the need for a purification treatment step to remove the catalyst contaminants from the produced nanotubes or fibers and provides a method of mass producing carbon nanotubes and carbon fibers with high efficiency." Harutyunyan expressed in 0029 that all this is done simply "By operating the device to magnetically confine the catalyst during the process..." Harutyunyan communicates the method of this confinement by using a field strength expressed in 0033: "The strength of the magnetic field generated by the device, at a minimum, should be high enough to influence the catalyst and at a maximum, the field should not substantially disrupt the process. In one aspect, the magnetic field generating device of the present invention can generate a magnetic field of about 100 gauss to as high as about 5000 gauss or higher, as it is believed that the higher magnetic field could be used with the present inventive apparatus and methods." It important to note here the Harutyunyan et al. explicitly limit the field here to intensities such that the normal catalytic activity is not disrupted. This intent of Harutyunyan et al. to limit the magnetic influence by field intensities much less than those sufficient to affect atomic electronic properties is further expressed in 0047 where they limit the temperature of the catalyst and the fields to intensities such that the catalysts

remain ferromagnetic for immobilization by the field. In 0047, Harutyunyan specifies "For example when employing transition metal based catalyst, the temperature of the catalyst is maintained below the Curie temperature of the particular transition metal is used. " On the contrary to Harutyunyan et al., the disclosure by Little, however, only considers fields strong enough such that the normal activity of the catalyst is disrupted judiciously such that the activity is increased. There is a natural line of distinction between these two disclosures of Harutyunyan et al. and Little. Harutyunyan et al. does not disclose any influence of the magnetic field on the intrinsic mechanism that occurs on carbon and metal atoms of and in the catalyst. In fact Harutyunyan et al. never mentioned a mechanism of CNT formation. As evidence of Harutyunyan et al non-enablement concerning the influence of magnetic field on the mechanism, 0042 is presented where Harutyunyan et al. disclose: " Contacting the carbon containing precursor with the catalyst at sufficient temperatures causes carbon deposits to form on the catalyst." Here in 0042 and elsewhere, they never consider how the magnetic field might affect the catalyst's intrinsic ability to deposit carbon articles. In fact in 0047 and 0048 they explicitly avoid such effects of the magnetic field on the catalytic mechanism. On the other hand as considered below, Little discloses the details of how a powerful enough dynamic external magnetic field not only simply immobilize the catalyst, but moreover (and much more importantly) how the magnetic field may judiciously be employed so as to drive the intrinsic mechanism of CNT and filament formation. Holding the catalyst is only a narrow aspect of the current disclosure of Little. I suggest that since the disclosure and aim of Harutyunyan et al. are only to immobilize the catalyst in their patent that they have rights only over field strength that serve this purpose of immobilizing the catalyst. They limit the field themselves in their patent. After all, in the disclosure of Harutyunyan et al. only the immobilization of catalyst by the magnetic field is enabled. Harutyunyan et al. in no way enable the magnetic field as an important instrument that influences the intrinsic mechanism of CNT and filament formation, such that the CNT and filament formation is improved, increased or even modified.

On this basis, I think Harutyunyan et al. would have unlimited claims if they claim intellectual property beyond that associated with merely holding or immobilizing the catalyst with the external magnetic field during growth for better separation, purification and catalyst recycle. On the other hand, this

new disclosure of Little goes far beyond Harutyunyan 's catalyst immobilization by enabling the intense external dynamic magnetic field to drive many important events associated with the intrinsic mechanism of CNT and filament formation. Harutyunyan et al. does not even mention a mechanism of CNT and filament formation in their disclosure, so I do not think they should rightful claim use of the field to control the mechanism of CNT and filament formation without even attempting to enable the magnetic field for such purposes. I argue that this is a lot for Harutyunyan et al. to anticipate especially considering they make no reference or connection nor provide any evidence of such relationship between magnetic fields and the mechanism of CNT and filament formation. By extending ownership to Harutyunyan et al. based on unfound and undemonstrated enablement with unlimited claims {all of which is because Harutyunyan et al. mentioned one aspect (immobilization) of the magnetic field under much weaker strength and intensity in their disclosure (not even considering other aspects and the broader significance thereof)}, this violates the first paragraph of 35 U.S.C. § 112.

The current invention of Little (contrary to Harutyunyan et al.) presents a detailed and thorough enablement of intense, dynamic magnetic field for causing the mechanism and moreover (aside from just the magnetic field) the invention discloses and enables the importance of a changing magnetic field for causing CNT and filament nucleation and growth. Harutyunyan et al. never even mention a changing field since this would defeat their purpose of immobilizing the catalyst. Therefore in addition to the enablement of the more intense magnetic field by the current disclosure, the disclosure further demonstrates the importance of field changing magnitude and direction in order to influence CNT and filament formation. The claims of the current disclosure are therefore modified so as to assert ownership of intellectual property associated with using magnetic field and dynamic magnetic fields to affect CNT nucleation and growth.

Next, I describe how the patent of Little enables an externally, intense ($>10^{-1}$ T) and dynamic magnetic field for causing, driving and controlling the mechanism of CNT and filament formation so that if intense enough ($>10^{-1}$ T) and changing (in intensity and direction), the external magnetic field can enhance CNT and filament yield, rate and quality. Throughout this short description magnetic field implies

both the intrinsic and possibly an externally reinforcing magnetic fields. The patent of Little enables by first in paragraph 63 revealing how a changing magnetic field in the nanoparticle varies the hydrocarbon decomposition rate at a preferred decomposing facet. Then in paragraph 64, I demonstrate how particle shape causes anisotropy of magnetic, spin density waves and gradients and waves that define the decomposing facet and the graphitizing facet, where the decomposing facet is the facet of lower coercivity. Next in paragraph 65, I describe the origin of spin density gradients and magnetic gradients on the basis of temperature gradients and the Curie temperatures. Then in paragraph 67, I show how these spin density gradients and magnetic gradients pull paramagnetic carbon atoms into the interior of the nanoparticle. In addition to the magnetic forces driving C atoms into the metal catalyst, I also in paragraph 70 reveal how the ferromagnetic effects of exchange weaken M-M bonds so that the energies of bond compression and stretching are reduced for lower activation of carbon diffusion in the metal. In paragraph 72, I demonstrate how the magnetic and spin density gradients in the direction of the graphitizing facet force carbon to this graphitizing facet. Paragraph 77 further demonstrates how an exchange gradient and anisotropy also drive carbon atoms to the graphitizing facet. One source of diffusion resistance in the catalyst is carbiding. Paragraphs 93 and 97 relate the metastability of carbides of Fe, Co and Ni to their ferromagnetism and hence the inhibition of carbiding by magnetic phenomena. Paragraphs 91 and 99 reveal how external magnetic fields might weaken carbide stability in other transition metals, allowing easier carbon diffusion that leads to better CNT and filament formation. Paragraph 101 shows how exchange gradients in the catalyst might contribute to rehybridization of C atoms as they move to the graphitizing facet. Paragraph 103 reveals how the exchange gradient and spin density wave produce a local maximum in magnetic field near the graphitizing facet, which assist the conversion of C_6 to C_5. C_5 being paramagnetic while C_6 being diamagnetic, the magnetic fluctuations assist the driving of some edge C_6 to C_5. Paragraph 105 further reveals how this magnetically induced C_5 formation in coordinated surface graphene sheets contribute to bending and CNT nucleation. So far the importance of spin density gradients, magnetic gradients and anisotropy reveal the importance of changing and varying magnetic fields on the mechanism of CNT and filament formation. Paragraph 108 shows how magnetic fields lower temperature for graphitization. Paragraph 110 shows how intrinsic and external magnetic fields stabilize metal to ligand electron transfer due to the high spin of the charge transfer complex. Such charge transfer weakens ligand (graphene) C-C

bonds allowing rearrangement from C_6 to C_5 for distortion and CNT nucleation. This type of charge transfer also assists the bond breaking and rearrangment needed to grow graphene sheets at the facet and later add C_6 units to the growing CNT sidewall. This electron transfer to graphene ligand is coupled to charge transfer to hydrocarbon at a distant facet and allows modulation of decomposition chemistry to graphitizing chemistry. The magnetic field of the catalyst may also stabilize the forming sidewall relative to the initial adjacent graphene sheet on the surface. Changing magnetic fields change electronic structure of the sidewall of the CNT and facilitate necessary rehybridization at the interface for conversion of C_6 to C_5 and C_7 and adding C atoms to C_5 and C_7 to form new C_6 rings for sidewall elongation. Here again a changing magnetic field is important for CNT and filament formation.

On the basis of this short description it is obvious that Little enables a dynamic magnetic field for driving and potentially controlling CNT and filament formation. Haratyunyan et al. present no such theoretical or experimental enablement. Actually Harutyunyan et al. discovery involved a totally different environment of much weaker magnetic field conditions. It is interesting at this time to consider the prior art of Sun et al. as pointed out by the examiner. The inventor did not know of this at this at the time of the patent. But considering this published work of Sun et al. is consistent with the invention of Little. Sun et al., determined that fields on the order of 1T result in the conversion of nanotubes to nongraphitic filaments. This finding of Sun et al. is not inconsistent with the disclosure of Little, if one considers that Sun et al. used an intense (1T) but static magnetic field. The disclosure of Little stresses not only the importance of intensity of the field but also a dynamic, changing field for CNT formation. Consistent with Little, the static magnetic field would disrupt the spin density and magnetic gradients and anisotropy in the particles thereby eliminating an important modulating factor of hydrocarbon decomposition and carbon diffusion and eliminating an important cause and driving force of graphitization and disclining/distortive CNT nucleation motive. The result of the static magnetic field as predicted by Little's disclosure is rapid carbon production, diffusion and accumulation for formation of filamentous carbon rods.

Brief Description of Several Views of the Drawing(s).

Figures 1A – 1E show illustrations of the overall mechanism of CNT formation by catalytic chemical vapor deposition (CCVD) on ferromagnetic and some paramagnetic metal particles (Case A metals).

Figure 1A illustrates the absorption of CH_4 (or other hydrocarbon vapor) on a specific facet of the catalyst particle.

Figure 1B illustrates the preferential decomposition of the hydrocarbon on this particular facet with the desorption of H_2 and the absorption of carbon into the particle.

Figure 1C illustrates the anisotropic diffusion of carbon atoms from the decomposing facet to the graphitizing facet due to temperature, concentration, density, magnetic, spin density and exchange gradients.

Figure 1D illustrates the graphitization of carbon at a specific graphitizaing facet of the particle relative to the magnetic moment of the particle.

Figure 1E illustrates the distortion of the graphene sheet at the graphitizing facet under catalytic, thermal, vibrational, electronic and magnetic forces.

Figure 1F-1J show an illustration of the overall mechanism for graphitic encapsulation of nonferromagnetic (case B2 and B4) transition metals.

Figure 1F illustrates the nonselective adsorption of hydrocarbon vapor on the nonferromagnetic particle.

Figure 1G illustrates the nonspecific catalytic decomposition of the hydrocarbon on the surface of the nonferromagnetic particle with the subsequent desorption of H_2 and limited absorption of carbon into the nonferromagnetic particle.

Figure 1H illustrates the limited accumulation of carbon in the nonferromagnetic metal particle.

Figure 1I illustrates the nonspecific precipitation of carbon at all facets of the nonferromagnetic particle.

Figure 1J illustrates the nonspecific catalytic graphitization of the precipitated carbon about all facets of the nonferromagnetic particle.

Figure 2 shows a schematic view of how a chamber may be assembled schematically in the bore of a solenoidal magnet for CCVD. It is important that this chamber may also be equipped with laser vaporization or arc vaporization units.

Figure 3 illustrates the selective chemisorption and decomposition of a hydrocarbon vapor at a specific facet of the ferrocatalyst under thermal, density, magnetic and exchange gradients and anisotropy.

Figure 4 illustrates the magnetic push of diamagnetic H_2 (desorption) away from the catalyst and the paramagnetic absorption of carbon atoms into the interior of the catalyst.

Figure 5 illustrates the various driving forces (thermal, concentration, density, spin density and magnetic gradients) causing the anisotropic diffusion of carbon atoms from the decomposing site to the graphitizing site.

Figure 6 illustrates possible reversible metal (case A) carbon chemical bond formation during carbon atom diffusion. Reversible carbiding does not poison the catalyst.

Figure 7 illustrates possible reversible metal (case B2) carbon bond formation during carbon atom diffusion. Reversible carbiding does not poison the catalyst, but for case B2 carbon eventually precipitates ad graphitizes about all surfaces.

Figure 8 illustrates possible irreversible metal (Case B3) carbon bond formation during carbon atom diffusion. Irreversible carbiding poisons the catalyst.

Figure 9 illustrates the accumulation of carbon at the graphitizing facet of (case A) ferromagnetic catalyst particles in a region of maximum magnetic field with rehybridization of carbon atoms and the coordinated formation of graphene sheets at this location under magnetic, electronic and cooler conditions.

Figure 10 illustrates the inward growth of a graphene sheet at the graphitizing facet of the particle, whereby the particle surface coordinates the growing graphene sheet and the metal to ligand electron transfer slows the decomposition chemistry at the decomposing site to regulate carbon flux and accumulation toward the graphtizing facet. The magnetic field stabilizes the coordinated charger transfer species due to the high spin.

Figure 11 illustrates the distortion of the coordinated graphene sheet and magnetic fluctuations facilitate the conversion of some diamagnetic C_6 rings to paramagnetic C_5 rings at the edge (thru bond magnetic effects). The inward motion of C_5 by bond switching mechanisms distorts the sheet at the surface nucleating CNT.

Figure 12 illustrates the thru space magnetic effect of the magnetic field of the particle repelling the diamagnetic C_6 rings in the graphene sheet, contributing another force to nucleate the CNT. The changing magnetic field in the particle facilitates the vibrations of the sheet to nucleate the CNT.

Figure 13 illustrates the development of C_6 rings in the sidewall and elongation of the sidewall in the fluctuating magnetic field of the catalyst. The magnetic field of the graphitizing facet repels diamagnetic C_6 rings parallel to the surface (in the initial graphene sheet) but stabilizes C_6 rings normal to the surface (in the growing sidewall) after distortion and CNT nucleation.

Figure 14 illustrates size effects of SWCNT nucleation and growth wherein smaller particles the edge atoms are more catalytically active to grow the sidewall and the diffusion length is shorter to the edge atoms to grow the sidewall as opposed to nucleate new inner tubes leading to SWCNT.

Figure 15 illustrates the size effect of MWCNT nucleation and growth wherein on larger particles the diffusion length to less active edge atoms is greater so carbon accumulation is more probable (relative to smaller particles) so that inner sheets and tubes also nucleate and grow as the outer tube grows leading to MWCNT development.

Figure 16 illustrates the size effect on filamentous formation wherein for really large catalyst particles the diffusion length and sheet size becomes too large for thermal, catalytic, electronic and magnetic effects to force the distortion of graphene layers so layers just stack to form solid graphitic filamentous rods.

Figure 17 shows a schematic view of the whole apparatus for the case of CCVD inner chamber, note laser vaporization and arc vaporization systems may easily be exchanged with the CCVD system in the magnet bore (20T).

Figure 18 illustrates the CVD of metal nanoparticles on a substrate in the system, the annealing and orientation of the metal particles and the formation of CNT using CH_4 in contact with these catalysts in the magnetic field (20T) at 1000 °C.